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Boosting Pharmaceutical Removal Using Iron-Based Nanoparticles and Natural Organic Matter Synergy

VERONIKA VESELSKÁ[1], GILDAS RATIÉ[2], JOSEF KAŠLÍK[3], DIEGO BARAGAÑO[4], ANAËLLE SIMONNEAU[5], THOMAS THIEBAULT[6] AND JAN FILIP[3]

[1]Czech Advanced Technology and Research Institute, Regional Centre of Advanced Technologies and Materials, Palacký University Olomouc, Křížkovského 511/8, 779 00 Olomouc, Czech Republic

[2]Nantes Université, Univ. Angers, Le Mans Université, CNRS, Laboratoire de Planétologie et Géosciences LPG UMR 6112, F-44000 Nantes, France

[3]Czech Advanced Technology and Research Institute, Regional Centre of Advanced Technologies and Materials, Palacký University Olomouc, Šlechtitelů 27, 779 00 Olomouc, Czech Republic

[4]Spanish Geological Survey (CN IGME, CSIS), Matemático Pedrayes 25, 33005, Oviedo, Spain

[5]ISTO, UMR 7327, Univ Orleans, CNRS, BRGM, OSUC, F-45071 Orléans, France

[6]METIS, Sorbonne Université, EPHE, Université PSL, CNRS, UMR 7619, 75005 Paris, France

Iron nitrides (nFeN) present a promising alternative for field-based water remediation, particularly in removing pharmaceutical pollutants (PPs), in alignment with European environmental policy priorities. This study compares the effectiveness of nFeN to nanoscale zero-valent iron (nZVI), a widely used material in groundwater treatment, through a combination of laboratory experiments and on-site applications. The focus is on how natural organic matter (NOM) influences the aging, stability, and reactivity of nFeN in different environmental settings.

The results demonstrate that nFeN is less susceptible to oxidation than nZVI and exhibits enhanced stability under varying conditions. However, its transformation strongly depends on site-specific factors. In organic-rich pristine environments, chukanovite was the dominant aging by-product, whereas in watershed contaminated with PPs, magnetite and akageneite were more prevalent. Hydrodynamic conditions further influenced nFeN longevity, with water flow rates playing a key role in oxidation behavior.

nFeN also proved to be a more efficient sorbent for PPs, particularly for positively charged and neutral compounds. Adsorption efficiency varied across different PPs, with charge interactions playing a crucial role. Venlafaxine and metoprolol (positively charged) showed the highest adsorption affinity, while diclofenac, ketoprofen (negatively charged) and oxazepam (neutral) exhibited minimal adsorption, increasing their mobility and potential for environmental dispersion. These differences in accumulation are likely driven by electrostatic interactions, adsorption/desorption dynamics, and competition with NOM.

These findings highlight nFeN as a stable and efficient advanced nZVI-based material for environmental cleanup, offering enhanced contaminant removal compared to conventional nZVI. Its improved stability and broader adsorption capacity make it a strong candidate for sustainable water remediation technologies.